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(54) **SCHEDULED LOAD OF HEADS TO REDUCE LUBRICANT MIGRATION ON POLE TIP AND DECREASE TIME TO READY**

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(58) **Field of Classification Search**
None
See application file for complete search history.

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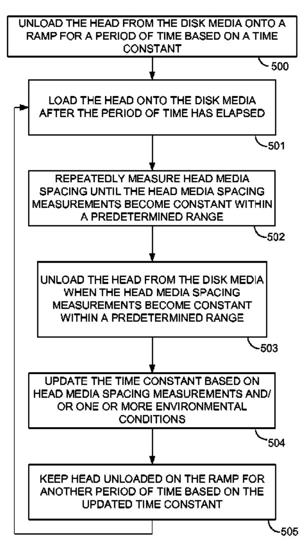
(57) **ABSTRACT**

A disk drive includes: a disk, a head, and control circuitry including a servo control system operable to actuate the head. The head is unloaded onto a ramp for a period of time based on a time constant. The head is loaded onto the disk after the period of time has elapsed and head-media spacing (HMS) is repeatedly measured. The head is unloaded when the HMS measurements become constant within a predetermined range.

24 Claims, 10 Drawing Sheets



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2011/0226729	A1	9/2011	Hogg	
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2012/0281963	A1	11/2012	Krapf et al.	
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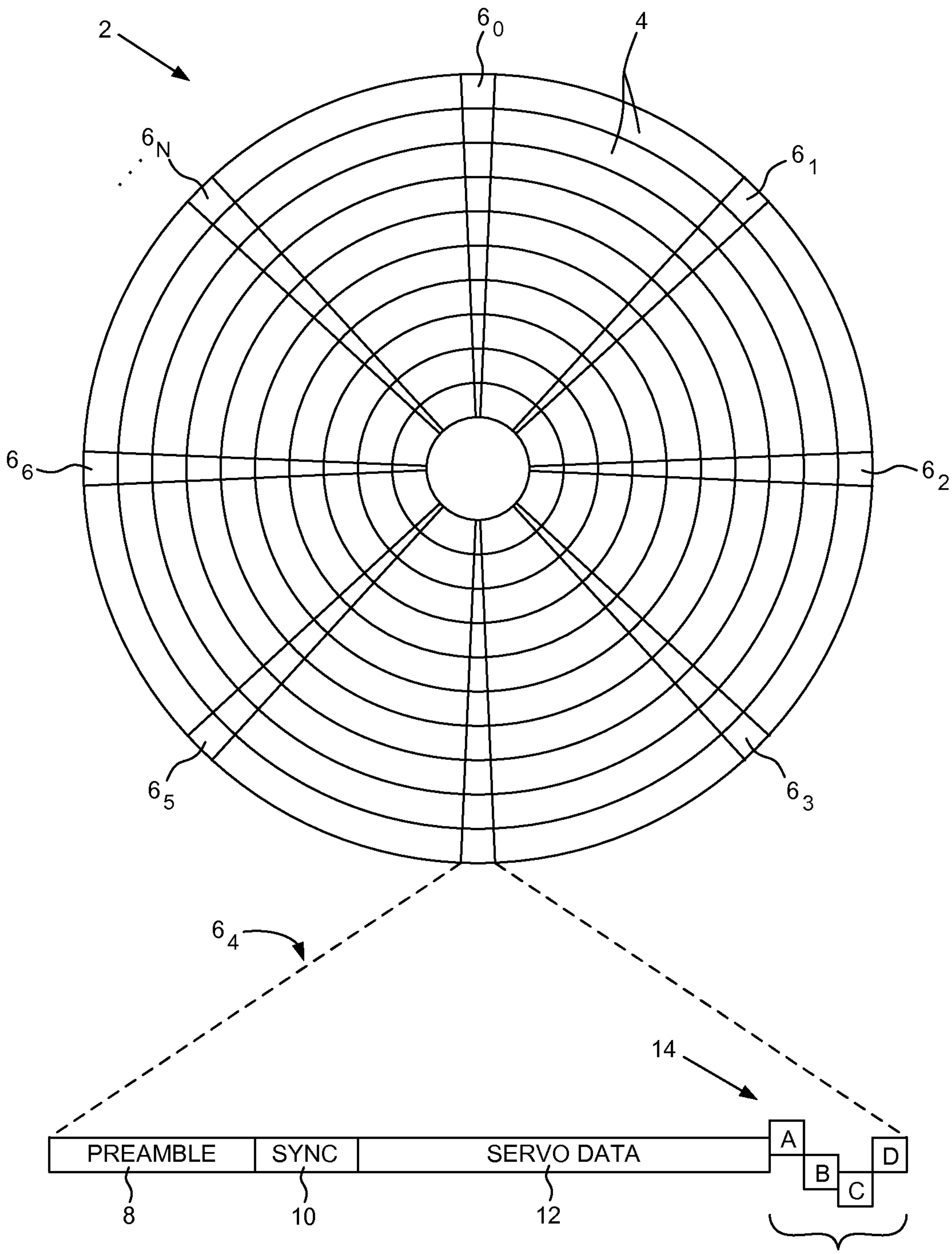


FIG. 1
(Prior Art)

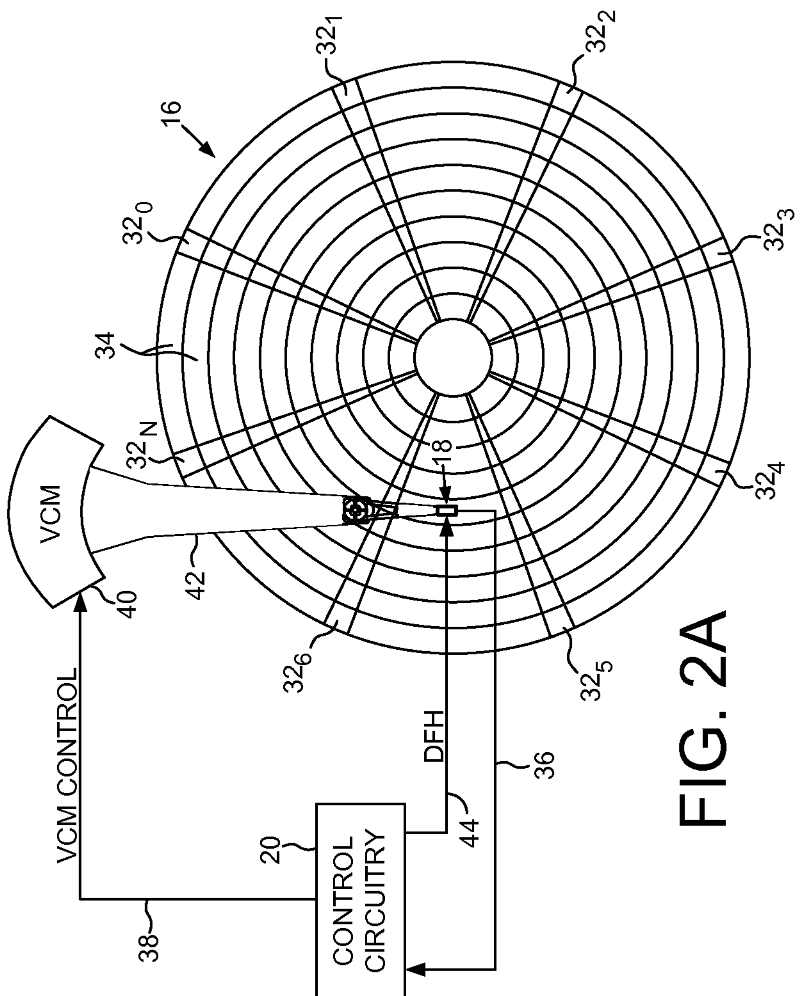

16
32_0
32_1
32_2
32_3
32_4
32_5
32_6
32_N
34
18
VCM
40
42
VCM CONTROL
38
20
CONTROL CIRCUITRY
DFH
44
36

FIG. 2A

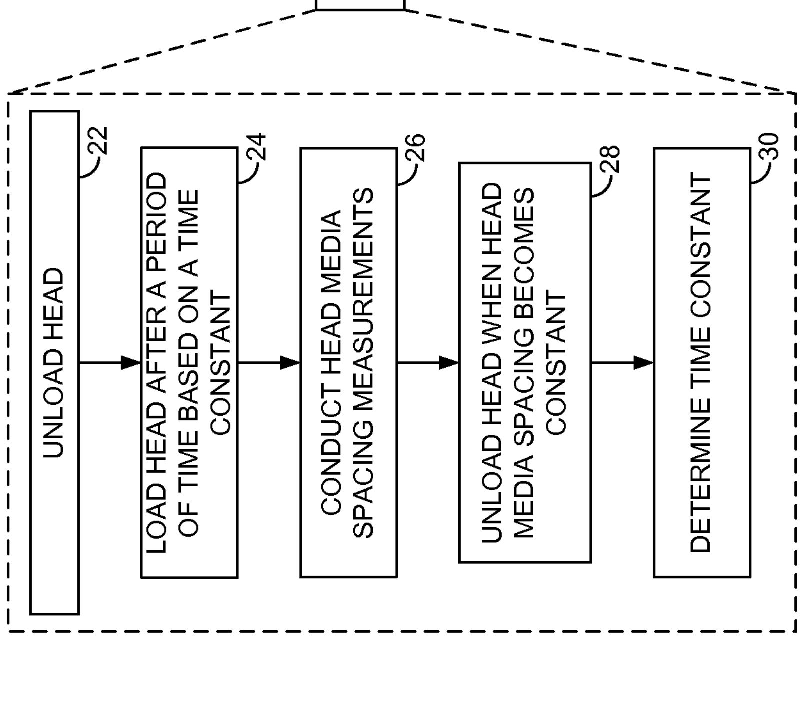

UNLOAD HEAD
22
LOAD HEAD AFTER A PERIOD OF TIME BASED ON A TIME CONSTANT
24
CONDUCT HEAD MEDIA SPACING MEASUREMENTS
26
UNLOAD HEAD WHEN HEAD MEDIA SPACING BECOMES CONSTANT
28
DETERMINE TIME CONSTANT
30

FIG. 2B

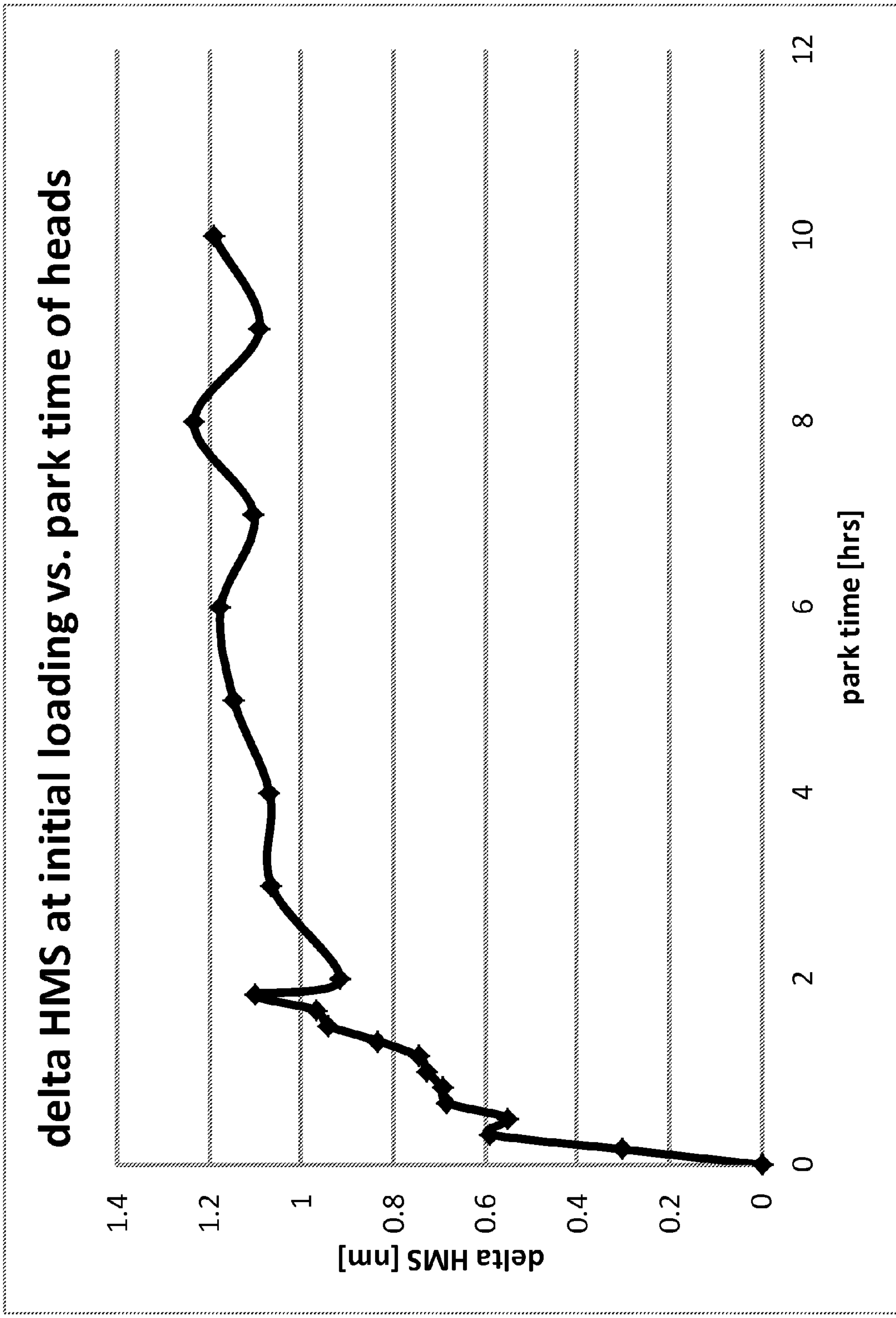

delta HMS at initial loading vs. park time of heads
delta HMS [nm]
1.4
1.2
1
0.8
0.6
0.4
0.2
0
park time [hrs]
0
2
4
6
8
10
12

FIG. 3

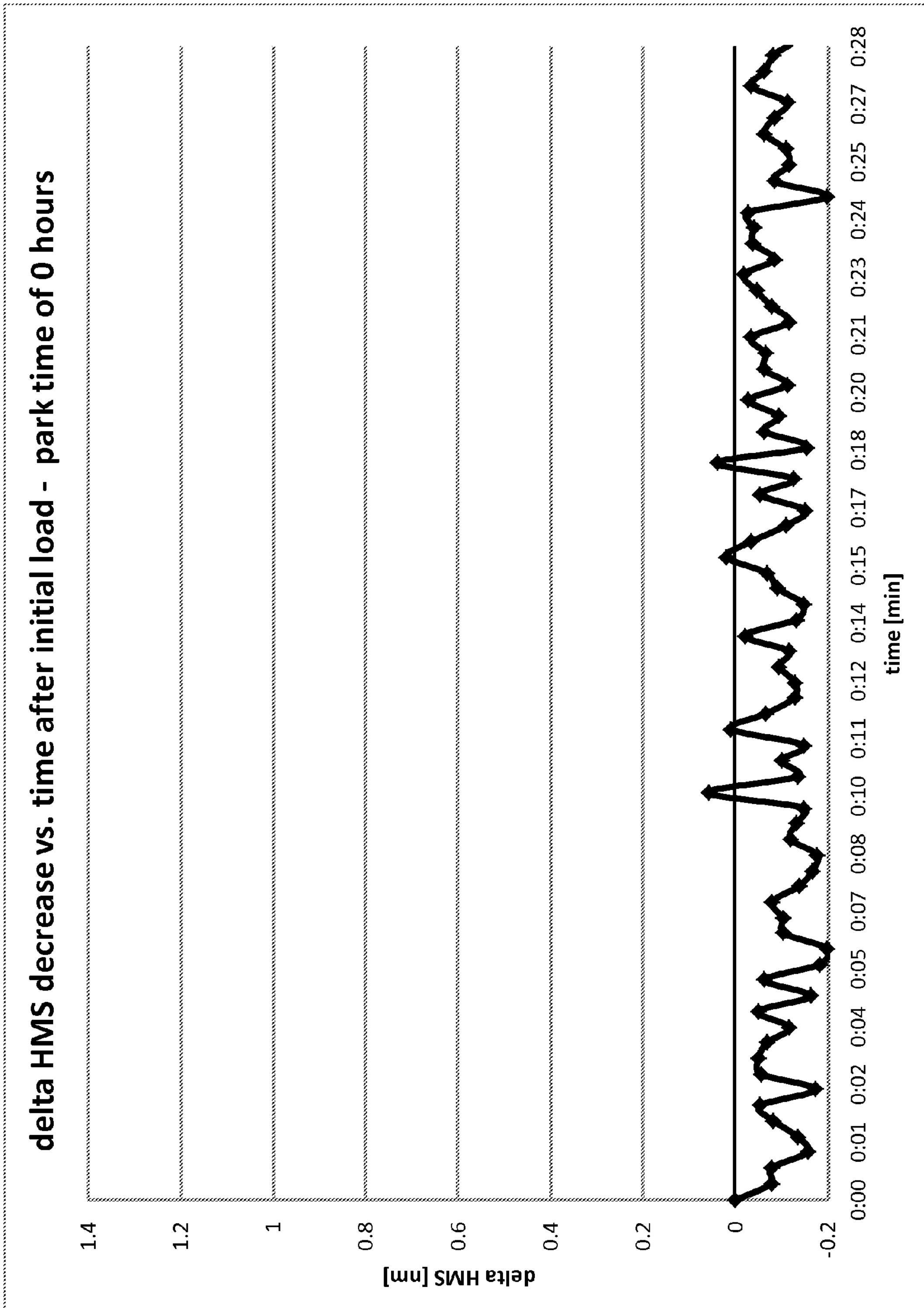

delta HMS decrease vs. time after initial load - park time of 0 hours
delta HMS [nm]
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0:00
0:01
0:02
0:04
0:05
0:07
0:08
0:10
0:11
0:12
0:14
0:15
0:17
0:18
0:20
0:21
0:23
0:24
0:25
0:27
0:28
time [min]

FIG. 4(a)

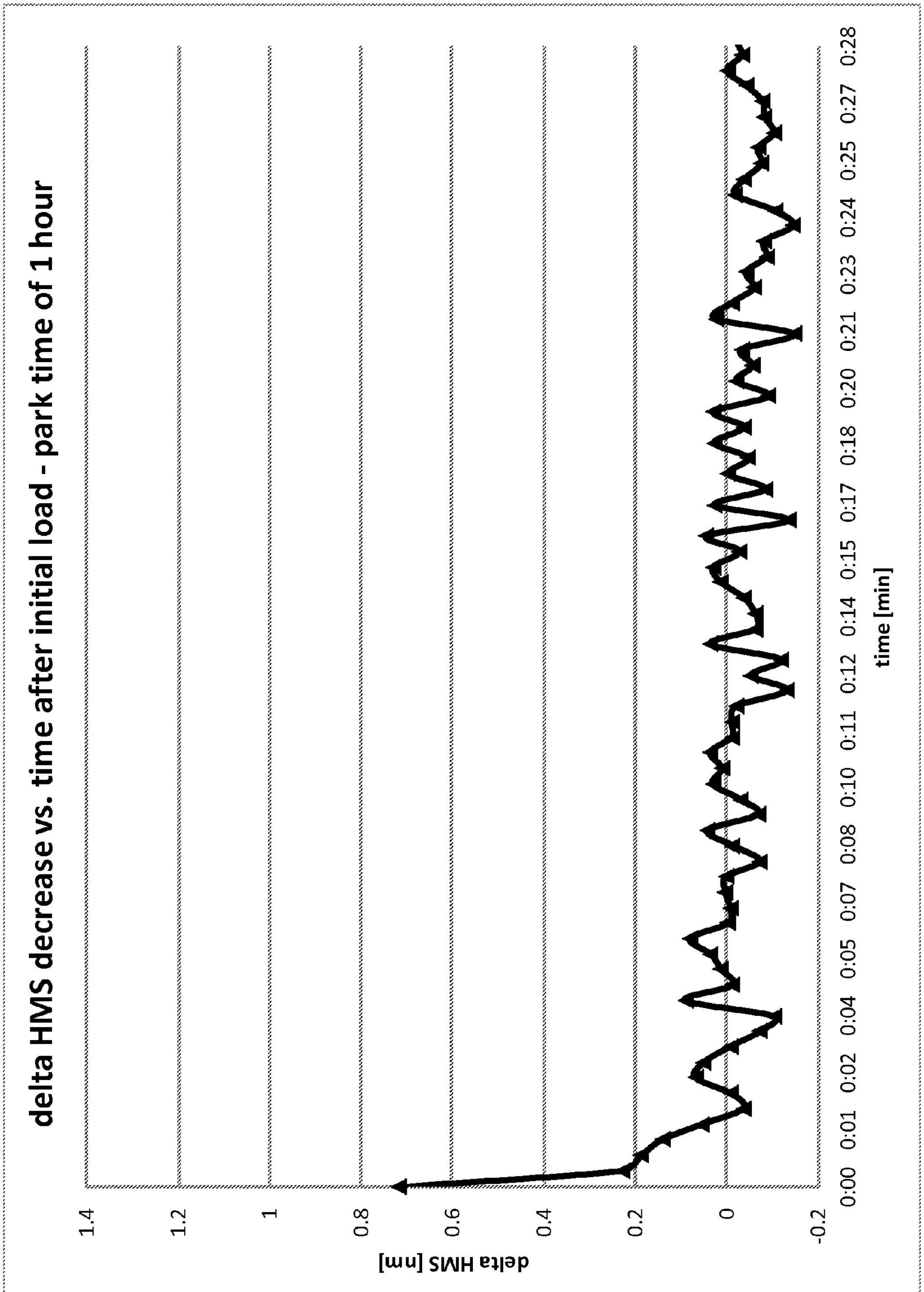

delta HMS decrease vs. time after initial load - park time of 1 hour
delta HMS [nm]
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
time [min]
0:00 0:01 0:01 0:02 0:02 0:04 0:04 0:05 0:05 0:07 0:07 0:08 0:08 0:10 0:10 0:11 0:11 0:12 0:12 0:14 0:14 0:15 0:15 0:17 0:17 0:18 0:18 0:20 0:20 0:21 0:21 0:23 0:23 0:24 0:24 0:25 0:25 0:27 0:27 0:28 0:28

FIG. 4(b)

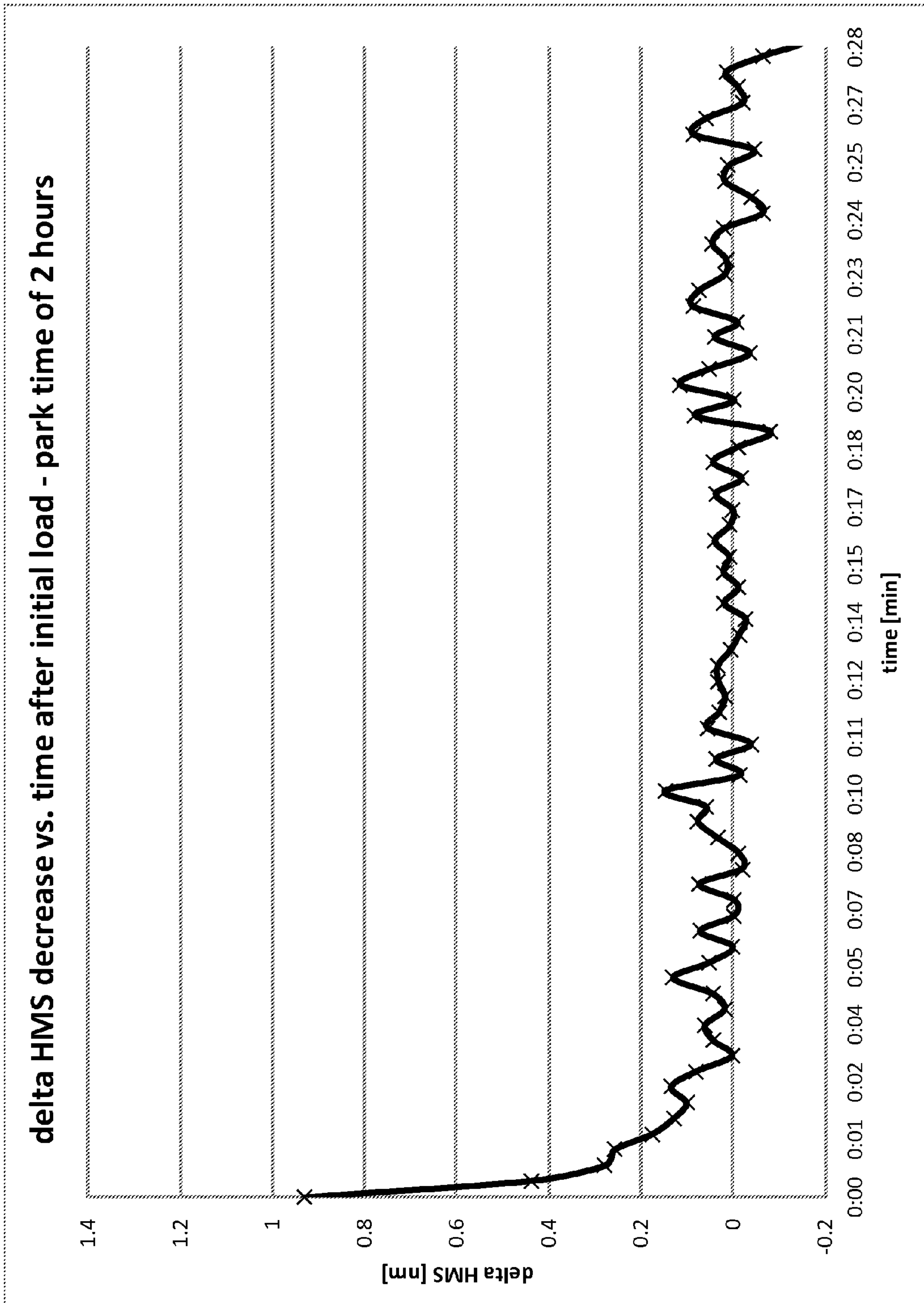

delta HMS decrease vs. time after initial load - park time of 2 hours
delta HMS [nm]
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
time [min]
0:00
0:01
0:02
0:04
0:05
0:07
0:08
0:10
0:11
0:12
0:14
0:15
0:17
0:18
0:20
0:21
0:23
0:24
0:25
0:27
0:28

FIG. 4(c)

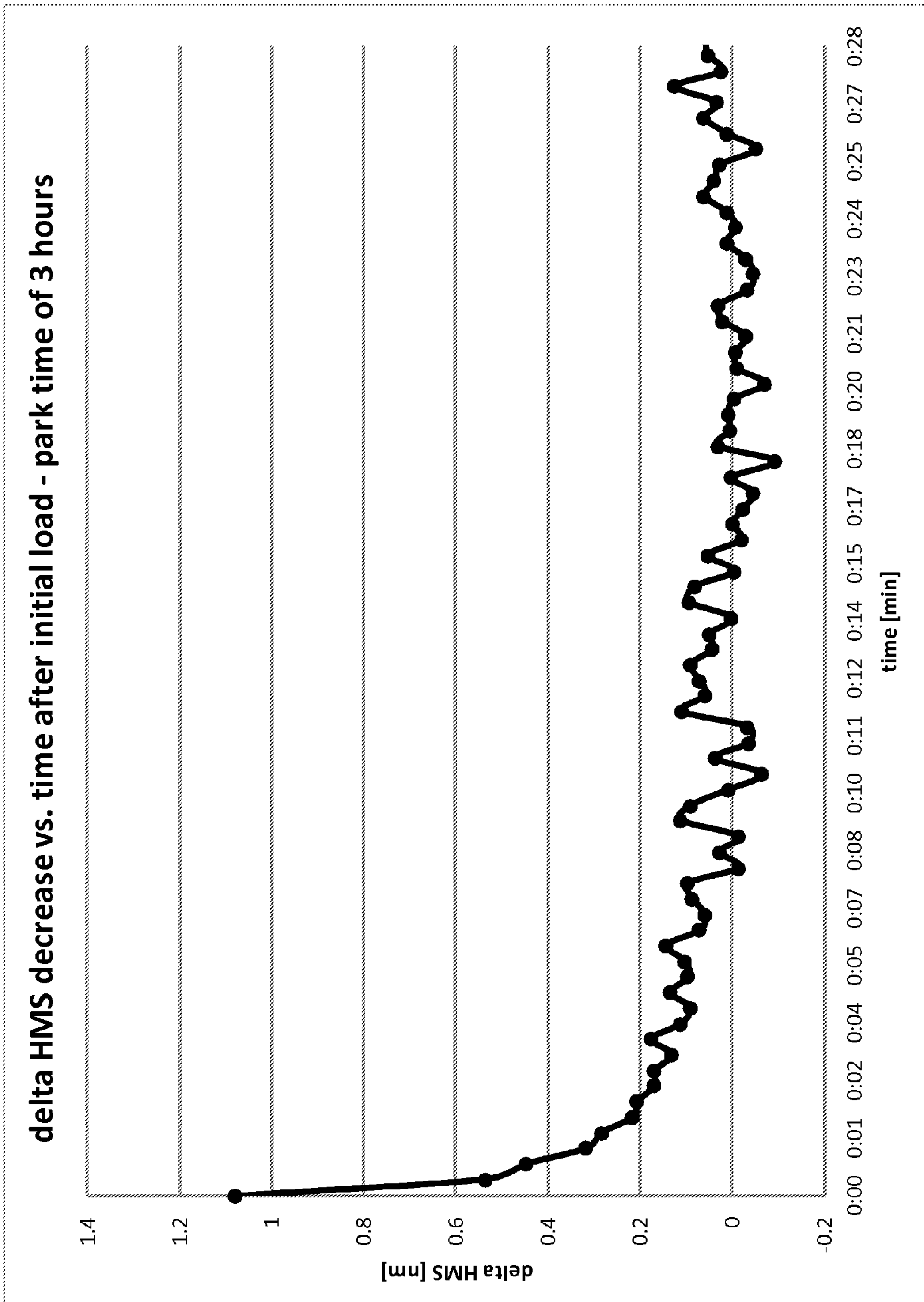

delta HMS decrease vs. time after initial load - park time of 3 hours
delta HMS [nm]
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0:00 0:01 0:02 0:04 0:05 0:07 0:08 0:10 0:11 0:12 0:14 0:15 0:17 0:18 0:20 0:21 0:23 0:24 0:25 0:27 0:28
time [min]

FIG. 4(d)

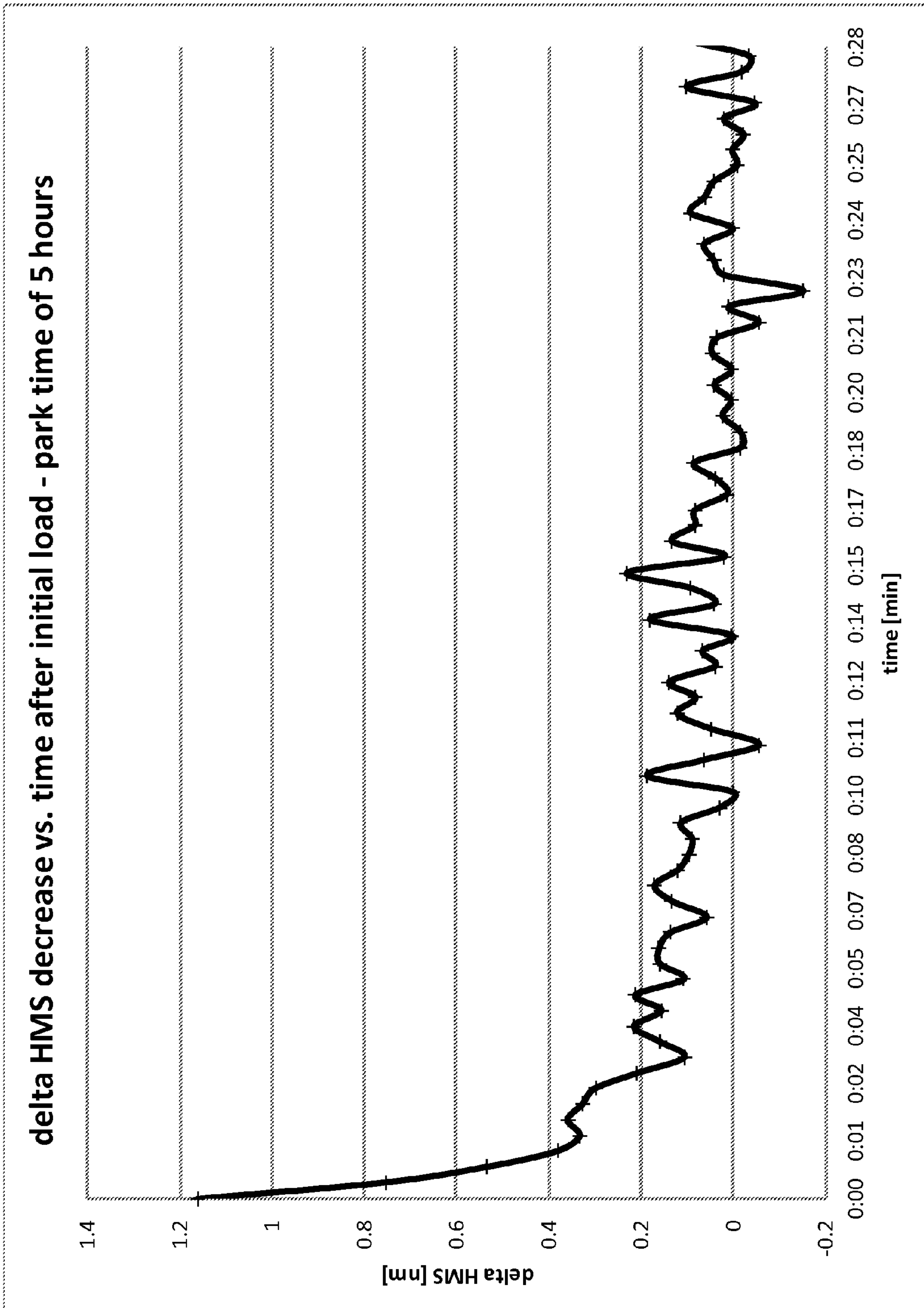

delta HMS decrease vs. time after initial load - park time of 5 hours
delta HMS [nm]
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0:00 0:01 0:02 0:04 0:05 0:07 0:08 0:10 0:11 0:12 0:14 0:15 0:17 0:18 0:20 0:21 0:23 0:24 0:25 0:27 0:28
time [min]

FIG. 4(e)

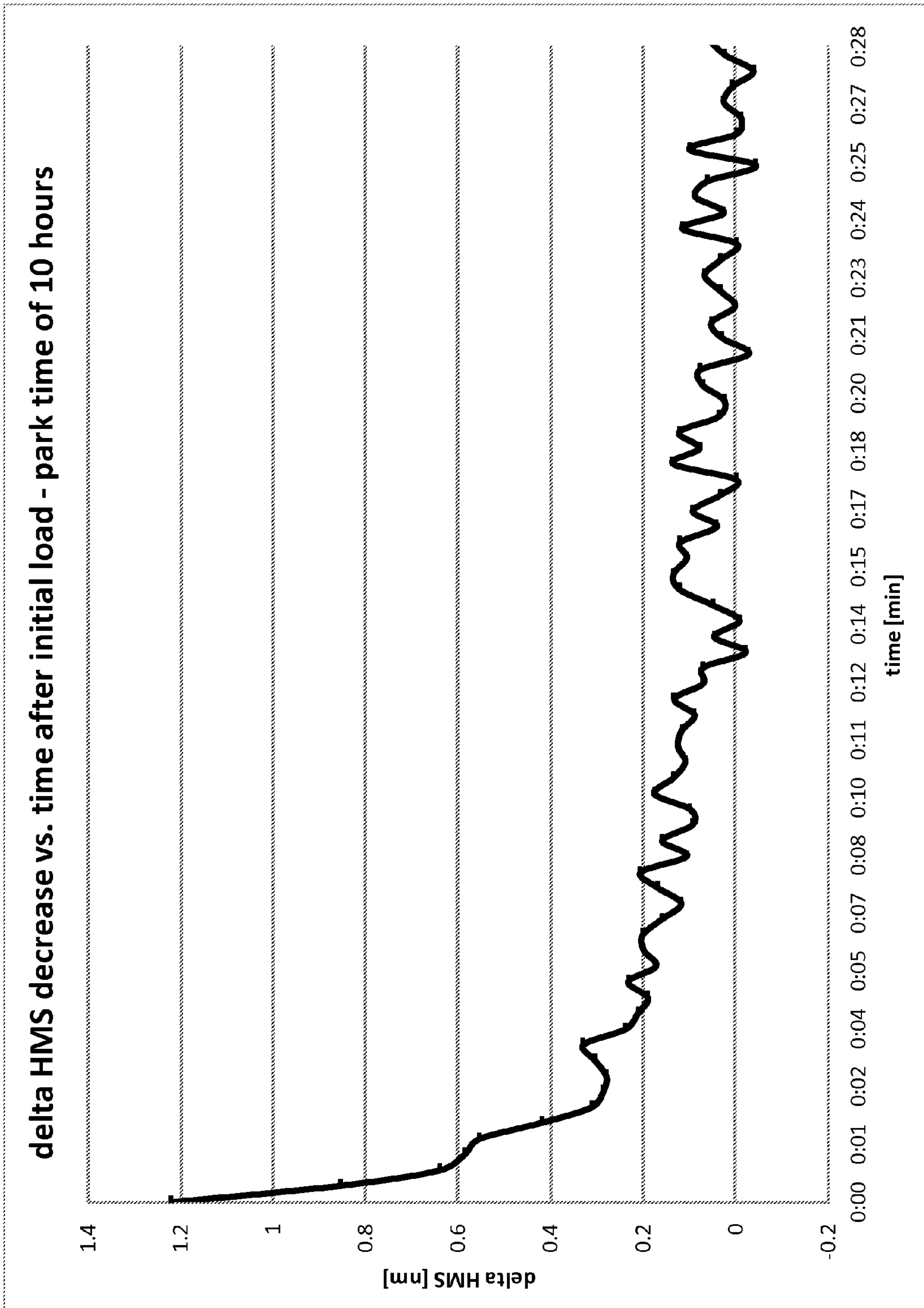
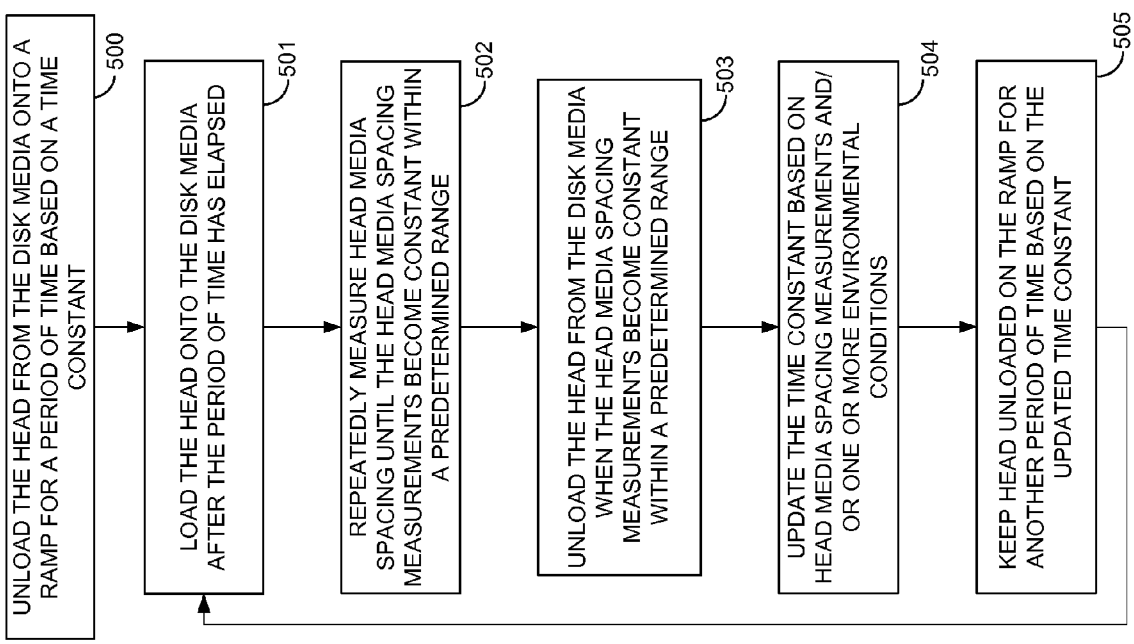

delta HMS decrease vs. time after initial load - park time of 10 hours
delta HMS [nm]
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0:00 0:01 0:01 0:02 0:02 0:04 0:04 0:05 0:05 0:07 0:07 0:08 0:10 0:10 0:11 0:12 0:12 0:14 0:14 0:15 0:15 0:17 0:17 0:18 0:20 0:20 0:21 0:23 0:23 0:24 0:25 0:25 0:27 0:27 0:28 0:28
time [min]

FIG. 4(f)

FIG. 5


UNLOAD THE HEAD FROM THE DISK MEDIA ONTO A RAMP FOR A PERIOD OF TIME BASED ON A TIME CONSTANT
500
LOAD THE HEAD ONTO THE DISK MEDIA AFTER THE PERIOD OF TIME HAS ELAPSED
501
REPEATEDLY MEASURE HEAD MEDIA SPACING UNTIL THE HEAD MEDIA SPACING MEASUREMENTS BECOME CONSTANT WITHIN A PREDETERMINED RANGE
502
UNLOAD THE HEAD FROM THE DISK MEDIA WHEN THE HEAD MEDIA SPACING MEASUREMENTS BECOME CONSTANT WITHIN A PREDETERMINED RANGE
503
UPDATE THE TIME CONSTANT BASED ON HEAD MEDIA SPACING MEASUREMENTS AND/ OR ONE OR MORE ENVIRONMENTAL CONDITIONS
504
KEEP HEAD UNLOADED ON THE RAMP FOR ANOTHER PERIOD OF TIME BASED ON THE UPDATED TIME CONSTANT
505

SCHEDULED LOAD OF HEADS TO REDUCE LUBRICANT MIGRATION ON POLE TIP AND DECREASE TIME TO READY

CROSS REFERENCE TO RELATED APPLICATION

This U.S. patent application is based on and claims the benefit of priority under 35 U.S.C. 119 from provisional U.S. patent application No. 61/809,805, filed on Apr. 8, 2013, the entire disclosure of which is incorporated by reference herein.

BACKGROUND

Disk drives comprise a disk media and a head connected to a distal end of an actuator arm which is rotated about a pivot by a voice coil motor (VCM) to position the head radially over the disk. The disk comprises a plurality of radially spaced, concentric tracks for recording user data sectors and embedded servo sectors. The embedded servo sectors comprise head positioning information (e.g., a track address) which is read by the head and processed by a VCM servo controller to control the velocity of the actuator arm as it seeks from track to track.

FIG. **1** shows a prior art disk format **2** comprising a number of servo tracks **4** defined by concentric servo sectors $\mathbf{6}_0$-$\mathbf{6}_N$ recorded around the circumference of each servo track, wherein data tracks are defined relative to the servo tracks **4**. Each servo sector $\mathbf{6}_i$ comprises a preamble **8** for storing a periodic pattern, which allows proper gain adjustment and timing synchronization of the read signal, and a sync mark **10** for storing a special pattern used to synchronize to a servo data field **12**. The servo data field **12** stores coarse head positioning information, such as a servo track address, used to position the head over a target data track during a seek operation. Each servo sector $\mathbf{6}_i$ further comprises groups of servo bursts **14** (e.g., A, B, C and D bursts), which comprise a number of consecutive transitions recorded at precise intervals and offsets with respect to a data track centerline. The groups of servo bursts **14** provide fine head position information used for centerline tracking while accessing a data track during write/read operations.

An air bearing forms between the head and the disk due to the disk media rotating at high speeds. Since the quality of the write/read signal depends on the fly height of the head, conventional heads (e.g., a magnetoresistive heads) may comprise an actuator for controlling the fly height. Any suitable fly height actuator may be employed, such as a heater which controls fly height through thermal expansion, or a piezoelectric (PZT) actuator. A dynamic fly height (DFH) servo controller may measure the fly height of the head and adjust the fly height actuator to maintain a target fly height during write/read operations.

In certain circumstances, lubricant on the disk media can build up on the head, causing high fly writes (HFW) due to increased head-media spacing (HMS). For example, if the head is parked on the ramp over an extended period of time (e.g., over one hour) then the lubricant may migrate from pooling areas back onto the air bearing system and the pole tip, which can result in a head-media spacing change that can cause HFW after initial loading of the heads back onto the media.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a prior art disk format having a plurality of servo tracks defined by embedded servo sectors.

FIG. **2**A shows a disk drive according to an example embodiment of the present inventive concept, having a head actuated over a disk by a servo control system.

FIG. **2**B is a flow diagram according to an example embodiment of the present inventive concept, where a scheduled load procedure is performed to remove or shear off the migrated lubricant from the pole area.

FIG. **3** illustrates a graph of the change in HMS versus the park time of the head.

FIGS. **4**(*a*) to **4**(*f*) illustrate a graph of the decrease in the HMS versus time after initial load, in accordance with an example embodiment.

FIG. **5** illustrates a flow diagram of an example embodiment of the present inventive concept.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

Some example embodiments described herein involve apparatuses and methods for determining or measuring the effect of parking the head on the ramp over an extended period of time, and scheduling a load and unload procedure for the disk drive to remove or shear off lubricant which may have migrated from the disk to the pole area of the head. Removing lubricant from the pole area of the head may result in decreasing the time-to-ready for the disk drive as well as preventing HFW. In the present application, "a head" and "the head" are not meant to be limited to one head, but can also be applied to one or more heads of the HDD, depending on the desired implementation.

FIG. **2**A shows a disk drive according to an example embodiment of the present inventive concept, having a disk **16**, a head **18**, and control circuitry **20** including a servo control system operable to actuate the head **18** over the disk **16**. The disk **16** includes embedded servo sectors $\mathbf{32}_0$-$\mathbf{32}_N$ that define a plurality of servo tracks **34**. The control circuitry **20** executes the flow diagram of FIG. **2**B. The operations in FIG. **2**B may be implemented, for example, in the hard drive firmware. When the hard disk drive is in operation, the heads are flying over the lubricated disk. Lubricant may be picked up by the head and may pool in certain areas on the head. When the hard drive is not in use, the head is unloaded and parked on the ramp, wherein lubricant may flow back onto the pole tip area (**22**). During this time, the lubricant may migrate from the pooling area back onto the air bearing slider and the pole area, which may increase the HMS. As a result of the lubricant migration, once the head is loaded back onto the disk, HFW may occur along with other issues, for example, longer time-to-ready for the disk drive. Thus, in order to eliminate the lubricant build up on the pole area of the unloaded head, after a period of time has elapsed based on a set time constant, the head is loaded to perform HMS measurements (**24**). The head is loaded periodically based on the set time constant to shear off the excess lubricant from the pole area. HMS measurements are performed until the HMS measurements become constant based on a desired HMS, which indicates that the migrated lubricant is cleaned off (**26**). When the HMS measurements become constant, the head is unloaded and parked on the ramp (**28**). The time constant may be adjusted based on the time taken for the HMS measurements to become constant (e.g., based on the read signal feedback) (**30**). Adjustment of the time constant can thereby allow the control circuitry to account for changes in environmental conditions (e.g., temperature changes, moisture, etc.), or variations in disk drive design. Further details are provided in the description of FIG. **5** below.

In the example embodiment of FIG. **2**A, the disk **16** comprises embedded servo sectors $\mathbf{32}_0$-$\mathbf{32}_N$ that define a plurality of servo tracks **34**. The control circuitry **20** processes HMS measurements **36** from the head **18** to implement the flow diagram as shown in FIG. **2**B. The control circuitry **20** generates a control signal **38** applied to a voice coil motor (VCM) **40** which rotates an actuator arm **42** about a pivot in order to actuate the head **18** to load the head to fly over the disk and to unload the head and park the head on a ramp.

FIG. **3** illustrates a graph of the change in HMS versus the park time of the head. As the park time of the head increases, the delta for the HMS also increases. As illustrated in FIG. **3**, a park time of three hours may result in the HMS being over 1 nm. In example embodiments, the set time constant may be configured to not exceed three hours, as the HMS will tend to exceed 1 nm after three hours, which may require a loading time of roughly thirty minutes or more to shear off the excess lubricant, as illustrated in FIG. **4**(*d*). In an example situation where the HDD may be powered down and the head may be parked, such as a server utilizing the HDD, the HDD can be configured to power on for the loading the head onto the disk media after a period of time has elapsed based on the set time constant, wherein the server or control circuitry of the HDD can monitor the time period to ensure that the head does not remain parked for more than three hours. However, depending on the desired implementation of the HDD, other configurations are also possible. For example, in a Redundant Array of Independent Disks (RAID) configuration or a tiered storage configuration wherein the HDD may be utilized only as a secondary storage with a set or known backup schedule, a maximum park time of five hours, for example, could also be employed.

FIGS. **4**(*a*) to **4**(*f*) are a series of graphs illustrating the decrease in the HMS versus time after initial load, in accordance with an example embodiment. The graphs illustrate the change in HMS versus time after initial load for a head that was parked on a ramp for 0 hrs, 1 hr, 2 hrs, 3 hrs, 5 hrs and 10 hrs, respectively.

In the example of FIG. **4**(*a*) the head is loaded almost immediately onto the disk (e.g. under one minute) after being unloaded from the disk and parked on the ramp. As illustrated in FIG. **4**(*a*), the HMS measurements are constant within a measurement error (e.g. 0.2 nm). In example embodiments, a predetermined range can be configured to compensate for such measurement error, so that the implementations can determine that the HMS measurements are constant when they fall within the predetermined range. The predetermined range can be configured manually, and/or can be derived from initial HMS measurements taken from loading the head immediately onto the disk for calibration (e.g., based on the measurement error), or by other methods depending on the desired implementation.

For long periods of unload where the head is parked on the ramp (e.g. 1 hr or more), the resulting increase in HMS may be up to 1 nm or more from the designated HMS of the disk drive. The head is therefore loaded until the increased HMS is reduced to zero, plus or minus a delta for measurement variance. The delta can be configured based on the design of the disk drive and the desired implementation.

As illustrated in FIG. **4**(*b*), parking the head on the ramp for 1 hr or less (e.g. 10-20 minutes) can reduce the increase in HMS, thereby reducing the time needed for the HMS measurements to become constant. For example, setting the time period for unloading the head for 10-20 minutes may require loading the head for only 30 seconds for shearing off the lubricant. For implementations where time periods of 1 hr or more are required (e.g. drive design, intended implementation of the disk drive, etc.), the time needed to reduce the HMS measurements may be longer (e.g., several minutes). As illustrated in FIGS. **4**(*c*) to **4**(*f*), a longer park time results in a larger initial difference in HMS, which may necessitate a longer loading period for the HMS values to become constant within the predetermined range. For example, as illustrated in FIG. **4**(*d*), a park time of three hours could require roughly ten minutes or more to reduce the HMS measurements to the predetermined range.

FIG. **5** illustrates a flow diagram according to an example embodiment of the present inventive concept. At **500**, the head of the HDD is unloaded from the disk media onto a ramp for a period of time based on a time constant as explained above. At **501**, the head is loaded onto a disk media of the HDD after the period of time has elapsed. At **502**, HMS is repeatedly measured until the HMS measurements become constant within a predetermined range. The measurements can be conducted, for example by a direct measurement of HMS from sensors or feedback from control circuitry. For example, a comparison of a read back signal strength from the head with a baseline read back signal strength can also be used to determine the HMS. As the read back signal strength is decreased, the control circuitry can determine the HMS based on the decreased read back signal strength due to a pre-determined correlation between the signal strength and the HMS. In another example implementation, the read back signal strength after the heads were loaded for a long period of time (e.g., 30 min or more) can be used as the HMS measurement, without having to determine the actual HMS. In this example implementation, because the baseline signal strength is known (e.g., preset in the control circuitry or predetermined from an example calibration measurement as described with respect to FIG. **4**(*a*)), the read back signal strength can be measured and the head can be unloaded until the read back signal strength falls within a predetermined range of the baseline read back signal strength.

At **503**, the head is unloaded from the disk media when the HMS measurements are constant within the predetermined range. At **504**, the time constant is updated based on the HMS measurements and/or one or more environmental conditions. Various environmental conditions may also affect the lubricant migration. For example, depending on the lubricant, lower temperatures may affect the viscosity of the lubricant, thereby requiring more time to shear off the lubricant than in a room temperature or warmer environment. Therefore, a temperature sensor may be employed to shorten the time constant if the temperature falls below a threshold for which the lubricant may shear off more slowly due to the lowered viscosity of the lubricant. In another example implementation where a vibration sensor is employed, the head may not be loaded immediately until the vibration conditions fall below a preset threshold to avoid damage to the disk media, even when the period of time based on the time constant has elapsed. Other configurations involving environmental conditions may also be employed, depending on the desired implementation. At **505**, the head is kept unloaded on the ramp for another period of time based on the updated time constant, wherein the flow repeats from **501**.

In another example implementation, a predetermined baseline HMS can also be used for direct comparison with the measured HMS to determine the time constant. The predetermined baseline HMS can be used with the predetermined range to ensure that the HMS is within a range of the baseline. If the measured HMS is compared to the predetermined baseline HMS to adjust the time constant, there may be a problem with signal degradation over time. In such implementations, the control circuitry can be further configured to adjust the baseline HMS to account for any signal degradation not related to lubricant migration over the head (e.g. contamination or wear in the head/disk interface). Once the measured HMS is constant over a period of time, the control circuitry can be configured using this value as the new predetermined HMS.

Any suitable control circuitry may be employed to implement the flow diagrams in the example embodiments of the present invention, such as any suitable integrated circuit or circuits. For example, the control circuitry may be implemented within a read channel integrated circuit, or in a component separate from the read channel, such as a disk controller, or certain actions described above may be performed by a read channel and others by a disk controller. In one example embodiment, the read channel and disk controller are implemented as separate integrated circuits, and in an alternative example embodiment they are fabricated into a single integrated circuit or system on a chip (SOC). In addition, the control circuitry may include a suitable preamp circuit implemented as a separate integrated circuit, integrated into the read channel or disk controller circuit, or integrated into an SOC.

In one example embodiment, the control circuitry comprises a microprocessor executing instructions, the instructions being operable to cause the microprocessor to perform the actions of the flow diagrams described herein. In some embodiments, certain actions may be omitted, combined, and/or performed in a different order than shown here. The instructions may be stored in any computer-readable medium. In one example embodiment, they may be stored on a non-volatile semiconductor memory external to the microprocessor, or integrated with the microprocessor in a SOC. In another example embodiment, the instructions are stored on the disk media and read into a volatile semiconductor memory when the disk drive is powered on. In yet another example embodiment, the control circuitry comprises suitable logic circuitry, such as state machine circuitry.

What is claimed is:

1. A disk drive comprising:
a disk media;
a head; and
control circuitry comprising a servo control system configured to actuate the head for reduction of lubricant migration, the control circuitry configured to:
unload the head onto a ramp for a period of time based on a time constant;
load the head onto the disk after the period of time has elapsed;
repeatedly measure head-media spacing (HMS) until HMS measurements become constant within a predetermined range; and
unload the head when the HMS measurements become constant within a predetermined range.

2. The disk drive of claim **1**, wherein the control circuitry is further configured to update the time constant based on a time taken for the HMS measurements to become constant within the predetermined range.

3. The disk drive of claim **2**, wherein the control circuitry is configured to unload the head when the HMS measurements become constant within the predetermined range for another period of time based on the updated time constant.

4. The disk drive of claim **1**, wherein the control circuitry is configured to measure HMS by comparison of a read back signal strength from the head with a baseline read back signal strength.

5. The disk drive of claim **1**, wherein the control circuitry is configured to update the time constant based on one or more environmental conditions.

6. The disk drive of claim **1**, wherein the period of time is configured to be less than three hours.

7. The disk drive of claim **1**, wherein the control circuitry is further configured to update a predetermined baseline HMS after the head is loaded for another period of time and repeatedly measure the HMS until the HMS measurements become constant.

8. The disk drive of claim **7**, wherein the another period of time is at least thirty minutes.

9. A method for mitigating lubricant migration onto a pole area of a slider in a hard disk drive (HDD), the method comprising:
unloading a head of the HDD onto a ramp for a period of time based on a time constant;
loading the head onto a disk media of the HDD after the period of time has elapsed;
repeatedly measuring head-media spacing (HMS) until HMS measurements become constant within a predetermined range; and
unloading the head when the HMS measurements become constant within the predetermined range.

10. The method of claim **9**, further comprising updating the time constant based on a time taken for the HMS measurements to become constant within the predetermined range.

11. The method of claim **10**, wherein the unloading the head when the HMS measurements become constant within the predetermined range is for another period of time based on the updated time constant.

12. The method of claim **9**, wherein the measuring HMS comprises comparing a read back signal strength from the head with a baseline read back signal strength.

13. The method of claim **9**, further comprising updating the time constant based on one or more environmental conditions.

14. The method of claim **9**, wherein the period of time is configured to be less than three hours.

15. The method of claim **9**, further comprising updating a predetermined baseline HMS after the head is loaded for another period of time and repeatedly measuring the HMS until the HMS measurements become constant.

16. The method of claim **15**, wherein the another period of time is at least thirty minutes.

17. A control circuitry configured to actuate a head of a hard disk drive (HDD) for reduction of lubricant migration, the control circuitry configured to:
unload the head of the hard disk drive (HDD) onto a ramp for a period of time based on a time constant;
load the head onto a disk media of the HDD after the period of time has elapsed;
repeatedly measure head-media spacing (HMS) until HMS measurements become constant within a predetermined range; and
unload the head when the HMS measurements become constant within a predetermined range.

18. The control circuitry of claim **17**, wherein the control circuitry is further configured to update the time constant based on a time taken for the HMS measurements to become constant within the predetermined range.

19. The control circuitry of claim **18**, wherein the control circuitry is configured to unload the head when the HMS measurements become constant within the predetermined range for another period of time based on the updated time constant.

20. The control circuitry of claim **17**, wherein the control circuitry is configured to measure HMS by comparison of a read back signal strength from the head with a baseline read back signal strength.

21. The control circuitry of claim **17**, wherein the control circuitry is configured to update the time constant based on one or more environmental conditions.

22. The control circuitry of claim **17**, wherein the period of time is configured to be less than three hours.

23. The control circuitry of claim **17**, wherein the control circuitry is further configured to update a predetermined baseline HMS after the head is loaded for another period of time, and repeatedly measure the HMS until the HMS measurements become constant.

24. The control circuitry of claim **23**, wherein the another period of time is at least thirty minutes.

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